Low Energy RHIC electron Cooling

Instrumentation

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MAC Review
8-10 December 2014

BROOKHAVEN NATIONAL LABORATORY
a passion for discovery

Office of Science
U.S. DEPARTMENT OF ENERGY

Outline

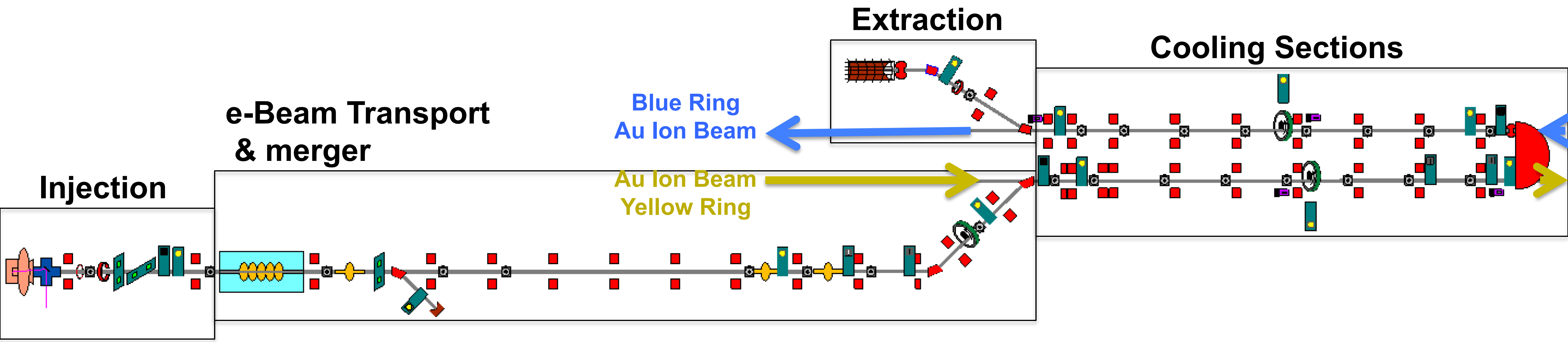
- Scope
- Electron Beam Parameters
- Instrumentation Parameters
  - Requirements & Capabilities
- Layout & Quantities by section
  - Injection
  - Transport
  - Cooling
  - Extraction
- Instrumentation Procurement & Repurpose
- Subsystem Details
  - Current: **ICT**, **DCCT**
  - Position: **BPM**
  - Profile & Emittance: **PM** & **Slit**
  - Energy Spread
  - Beam Loss: PMT type **BLM**
  - Scrapers: **SCPR** – H & V
  - Recombination Monitor
  - RHIC Diagnostics
- Summary

Scope

Beam Instrumentation & Measurements:

Position	Halo
Current	Emittance
Profile	Energy Spread
Loss	Alignment or Overlap
	Cooling Effect

Installation location
RHIC Sector 2

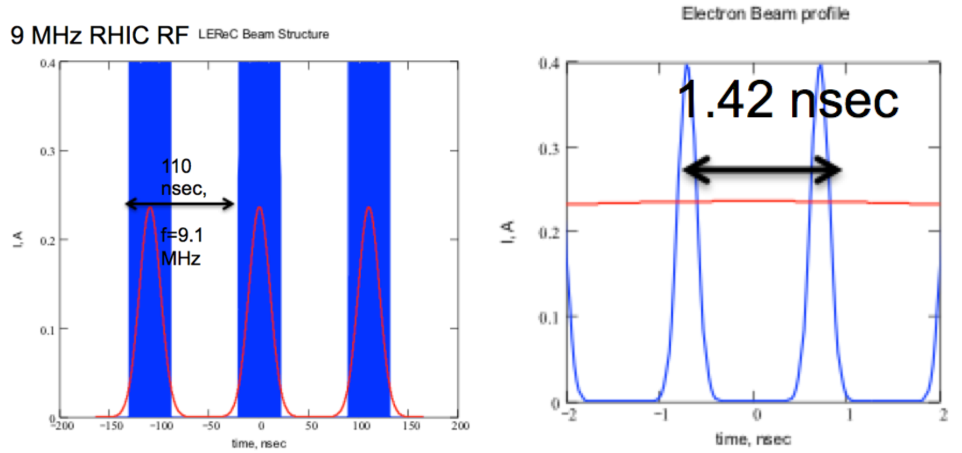


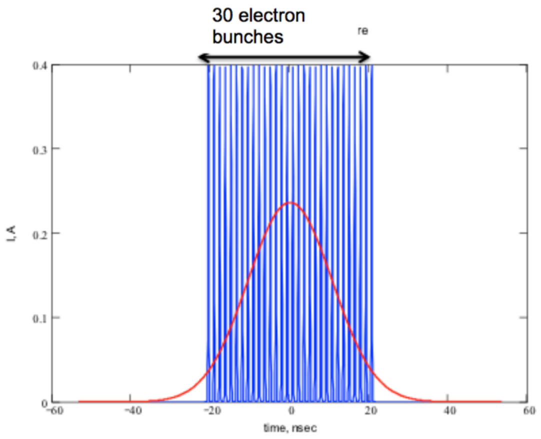
Electron Beam Parameters

e-Beam Parameters	Phase I	Phase II
Electron beam kinetic energy	1.6 – 2 MeV	up to 5 MeV
Total charge per bunch train, nC	3 nC (30x100pC)	5.4 nC (18x300pC)
Normalized rms emittance	< 2.5 um	<2 um
RMS bunch size	4.3 mm	2.7 mm
Bunch / Macrobunch Length	100 ps / 42 ns	100 ps / 42 ns
Average current	30 mA	50 mA
RMS energy spread	<5e-4	< 5e-4
RMS angular spread	<150 urad	<100 urad
Beam Power	50 kW	90 kW

Example Bunch Structure for Phase I:

Train of 3 nC macrobunches @ 9.1MHz rep rate,
each containing 30 x 100 pC bunches @ 704MHz rep rate.



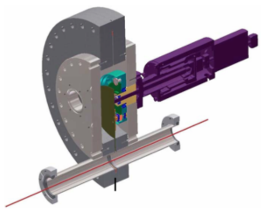


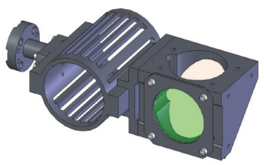
Instrumentation Parameters, e-beam transports

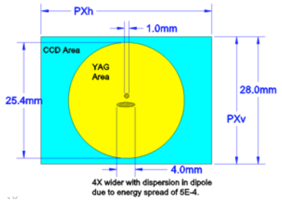
	1.6 to 5MeV e-beam transport instrumentation parameters				
		Required	Instrument Resolution/ Accuracy	Method	Notes
☐	Beam Position	50µm	10µm/ 50µm	BPMs (9.3mm buttons) with Libera electronics	Reuse Libera's from ERL, these have 703MHz BP filters, averaged data, not bunch-by-bunch
☑	Transverse Profile	100µm	50µm	(Low Power) YAG screen & CCD	Reuse 5 ERL profile monitors from Radiabeam, these have image bypass cages, 50µm resolution.
		100µm	50µm	(High Power) Cornell flying wire	Cornell claims 30u's resolution. 9u carbon fiber at 20m/s, detect x-rays with PMT.
☑	Bunch Charge		1-10 pC (noise floor)	Bergoz ICT, BCM-IHR, 10kHz max rate	1 - 3 nC typical per bunch train, 100-300pC/bunch Calibrate charge per laser pulse
☑	Bunch Charge Stability	<7% Turn x Turn	1%	Laser pulse x pulse amplitude measurement with fast photodiode	Compare pulses @ 78kHz for <7% variation turn x turn
☑	Beam Current	30µA (0.1% BC)	5µA	Bergoz matched NPCT aka "DCCTs"	20mA, 200mA ranges, differential and absolute measurements at injection and dump.
		(TBD)	30µA	Dump Faraday Cup Gated Integrator (pulse mode) Electrometer (CW mode)	Isolated dump as a Faraday Cup. (0.1% of max beam current)
☑	Beam Loss	10µA	5uA (TBD)	Differential DCCT measurement	Difference of injection and dump DCCTs
		10µA-sec (from ERL)	1uA	PMT detectors with JLAB VME electronics	Designed for a sensitivity of 0.1 – 6 µA of beam loss and an integrated trip limit of 10 – 60 µA•ms
☑	Emittance	10%	10%	Plunging multi-slit mask & Profile Monitor	Space charge dominated beams typical expected emittance 1mm-mrad
☐	Energy Spread	Δp/p <2e-4	TBD	Cornell deflecting cavity	Cornell claims 1e-4 resolution
			<10% of max Δp/p	YAG in dispersive section	Optional electron spectrometer beamline in two locations (Max. Δp/p = 5e-4)

Instrumentation Parameters Table LEGEND

Design Complete
Under Development
High Risk





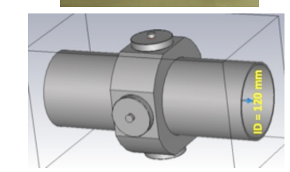


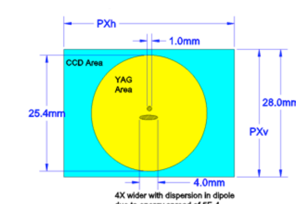
Instrumentation Parameters, RHIC ion beams

RHIC ion beam instrumentation parameters, 7.7GeV & 9.1GeV Au-beam				
	Required	**Instrument Resolution/ Accuracy**	**Method**	**Notes**
☑ **Beam Position**	10µm/ 100µm	10µm/ 100µm relative	RHIC in Q3 & Q4 cryostats: Stripline BPMs with RHIC legacy electronics	High resolution provided by averaging over many bunches.
☑ **Transverse Profile**	10%	<10µm	RHIC H & V IPMs	Located in sectors 2 and 12, Blue beam size measured with <10um resolution using vertical IPM in run-14
☑ **Bunch Charge**	TBD	50 pC	RHIC DCCTs and WCMs	expect up to 0.75e9 ions/bunch
☑ **Beam Current**	TBD	10µA	RHIC DCCTs	240mA typical, absolute measurements in sector 2
☑ **Beam Loss**	TBD	1µA	RHIC BLM system	Existing system
☑ **Emittance**	TBD	10%	Use RHIC IPM and lattice functions	RMS normalized emittance 2.5 mm mrad
☑ **Energy Spread**	Δp/p <5e-4	1%/ 5%	IPM, Tune meter?	

Instrumentation Parameters, Cooling region

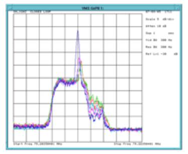
	Cooling Region Parameters, 1.6 to 5MeV e-beam, 7.7GeV & 9.1GeV Au-beam					
			Required	**Resolution/ Accuracy**	**Method**	**Notes**
☐	**Beam Position**	**Electrons**	30µm/ 100µm	10µm/ 50µm	BPMs with ***SHARED*** 28mm buttons Dual plane stations	BNL Zync Electronics VME boards ring **700MHz** front end filter for averaging over many electron bunches
☐		**Au Ions**	30µm/ 100µm	10µm/ 50µm	BPMs with ***SHARED*** 28mm buttons Dual plane stations	BNL Zync Electronics VME boards ring **39MHz** front end filter for averaging over many ion bunches
☑	**Transverse Profile**	**Electrons**	10%	50µm	(Low Power) YAG screen & CCD	New units similar Radiabeam models from ERL (includes impedance matching cages)
☐		**Electrons & Au Ions**	10%	50µm	(High Power) Cornell flying wire	Cornell claims 30u's resolution, 9u carbon fiber at 20m/s, detect x-rays with PMT.
☑		**Au Ions**	10%	<10µm	(High Power) RHIC H & V IPMs	Located in sectors 2 and 12
☑	**Beam Loss Electrons**		1µA	1µA	PMT detectors	10uA loss limit for machine protection
					JLAB VME electronics	instrumentation for transport efficiency tuning
☑	**Emittance Electrons**		10%	10%	Plunging Multi-slit	Space charge dominated beams
					Profile Monitor	typical expected emittance 1mm-mrad
☐	**Energy Spread Electrons**		Δp/p <2e-4	<10% of max Δp/p	YAG with double slit and dipole in dog-leg and in 180° dipole	Optional electron spectrometer beamline in two locations (Max. Δp/p = 5e-4)

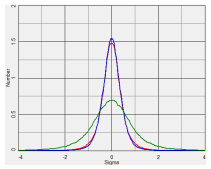




Instrumentation Parameters: Recombination, Cooling, and Machine Protection

Recombination instrumentation parameters				
	Required	**Resolution/ Accuracy**	**Method**	**Notes**
Recombined ions		Counts	Scintillator & PMT at centralized ion loss point with counting electronics	Lattice simulation predicts lattice aperture acceptance of Au^{+78} ions.
Recombination radiation (conceptual idea)		Counts	Scintillator & PMT with Counting electronics	Count 800keV x-rays emitted in the cooling region
RHIC Cooling instrumentation parameters				
Beam Alignment For Cooling		spectrum	Schottky Cavity HF: f=2GHz, Q=4700	spectra of the beam will show peaks resulting from cooling and thus beam alignment
		spectrum	Stochastic Cooling WB-RF Pick-Ups	
Ion transverse profile		Profile	RHIC H & V IPMs	IPM will show changes in transverse beam profile resulting from cooling.
Machine protection instrumentation parameters				
Beam Position variation	100µm	10µm	BPM	BPM electronics inhibit laser if beam wanders out of defined window.
Beam Loss	Interlock: 10µA Loss	1µA	BLM system	Fault studies help determine BLM threshold settings
			differential DCCTs	Differential DCCTs sensitivity ~5µA





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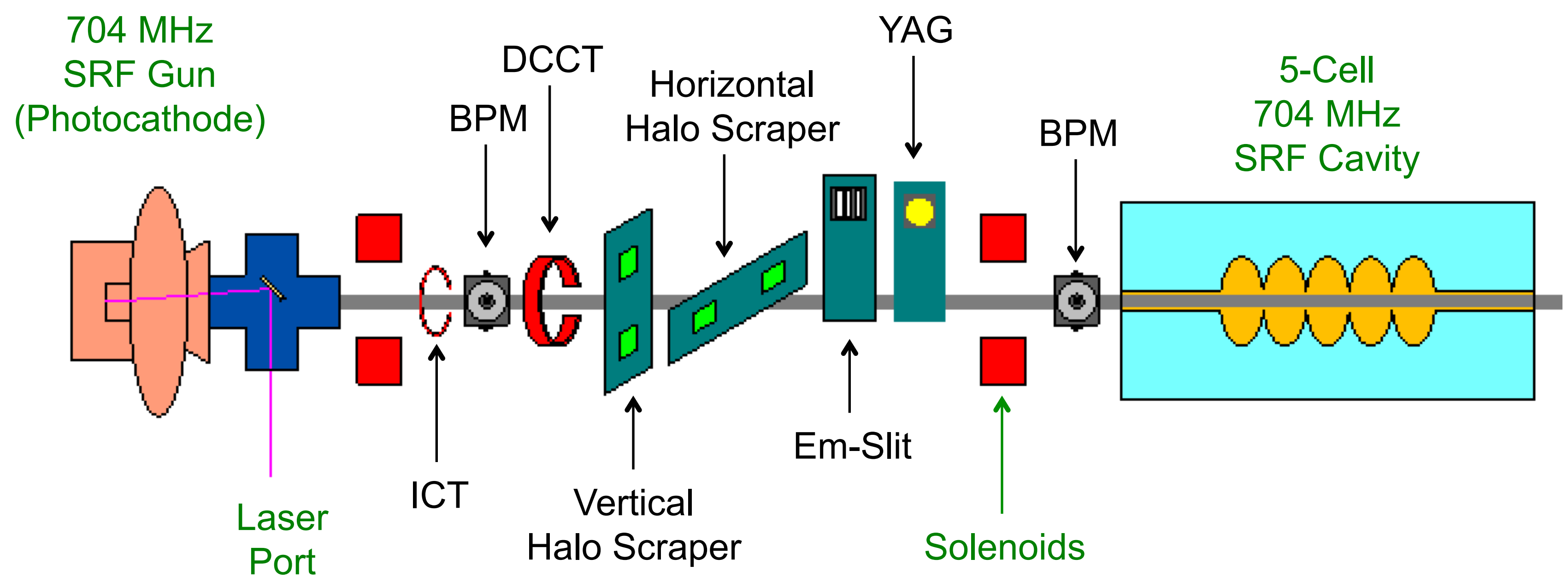
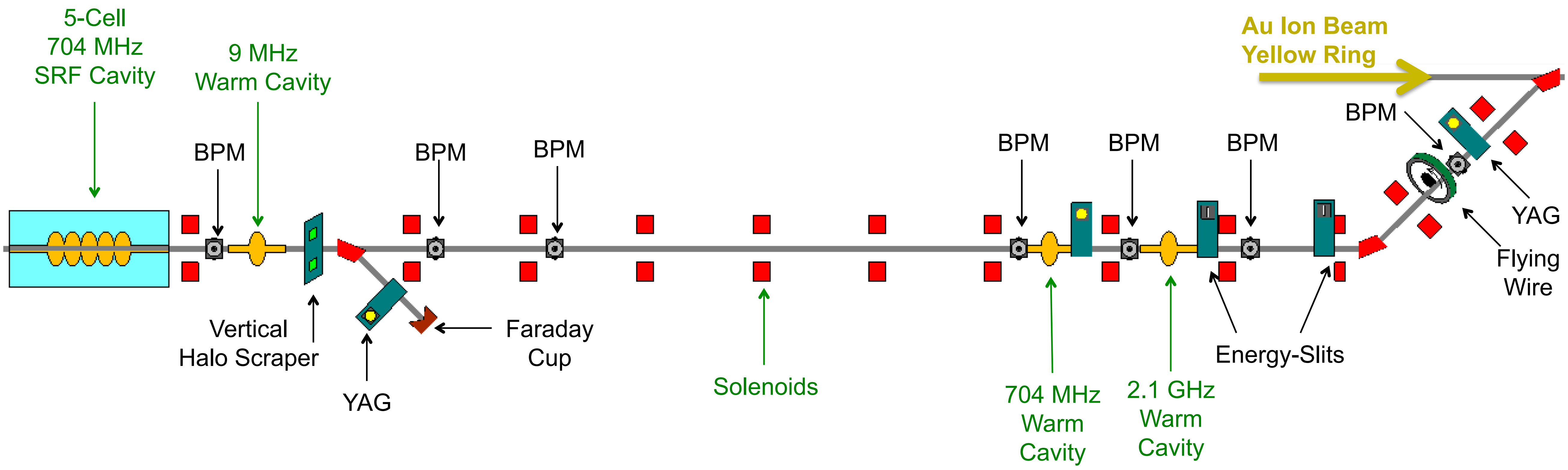
Scope: Injection



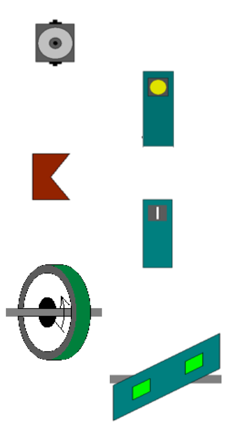
Injection

- BPM = 2
- YAG = 1
- ICT = 1
- DCCT = 1
- Emittance Slit = 1
- Scraper Pairs = 2

Scope: Transport

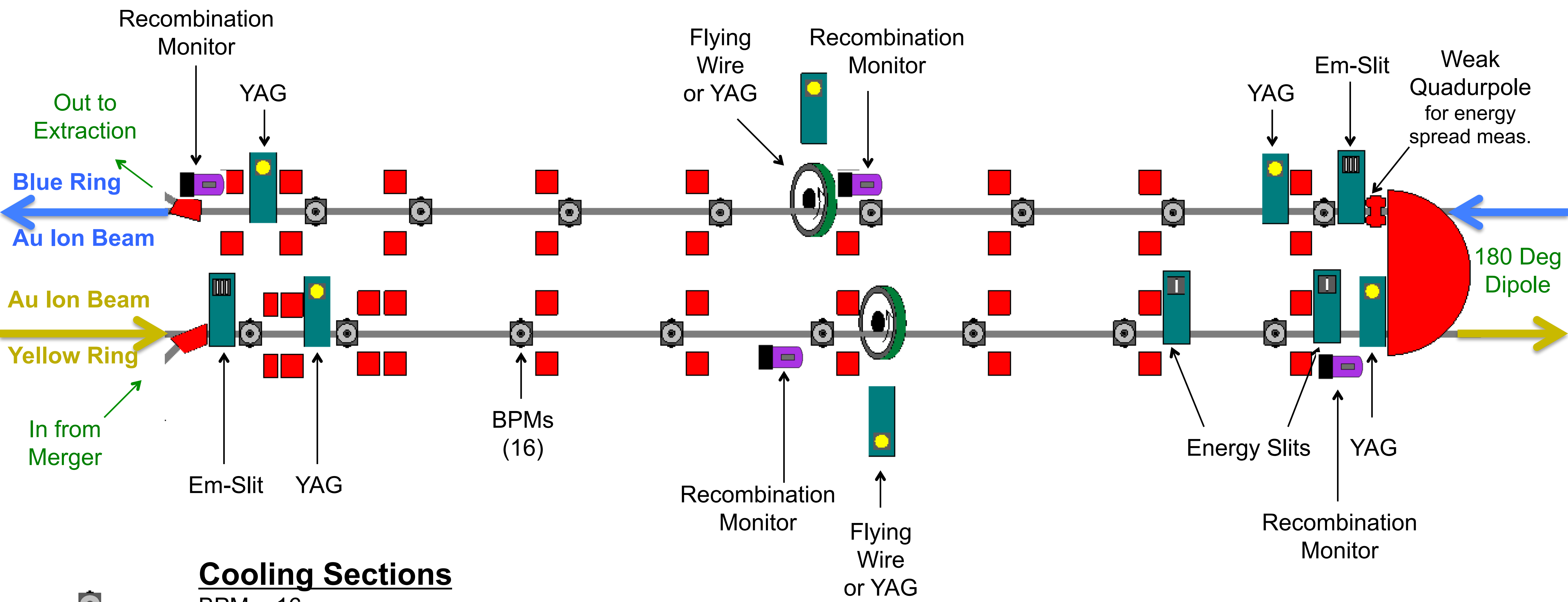


e-Beam Transport



BPM = 7
YAG = 3
Faraday Cup = 1
Energy Slit = 2
Flying Wire = 1
Halo Scraper Pair = 1

Scope: Cooling Sections



Cooling Sections

BPM = 16

YAG = 4 (or 6)

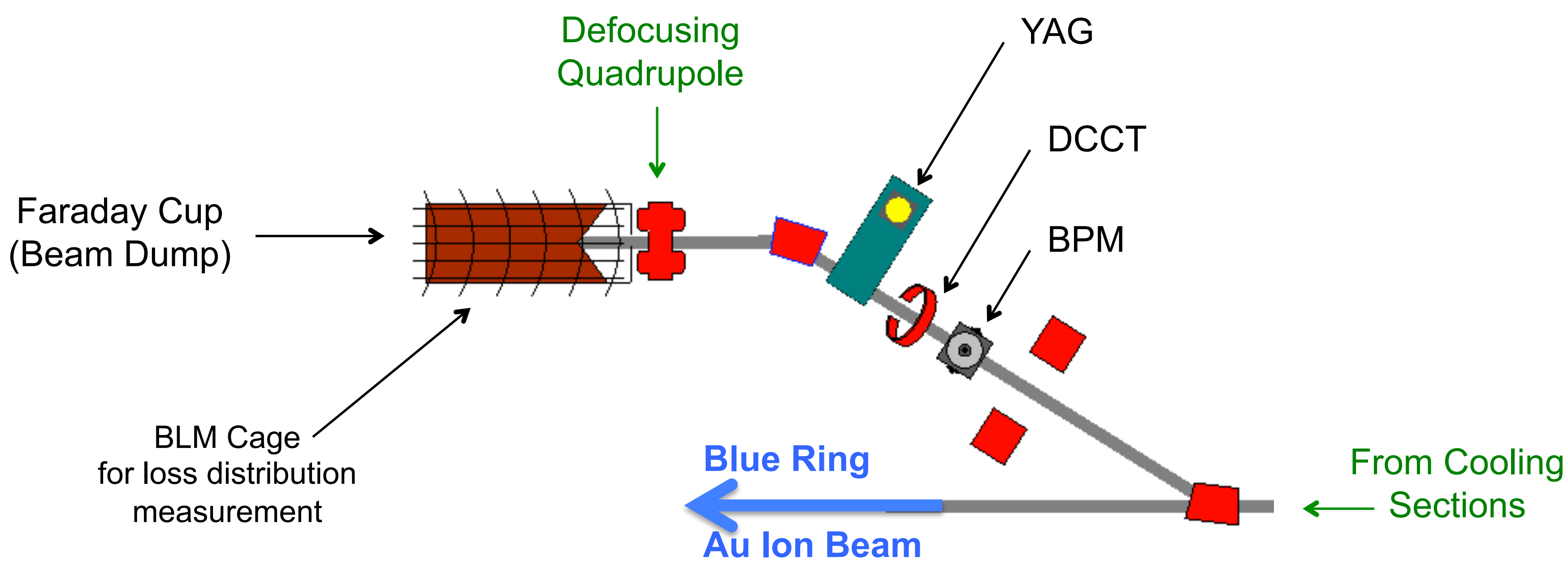
Flying wire = 2 (or 0)

Emittance slits = 2

Energy Slits = 2

Recombination Mon = 4

Scope: Extraction



Extraction

- BPM = 1
- YAG = 1
- DCCT = 1
- Faraday Cup = 1

Instrumentation Procurement & Repurpose

Item	Existing in ERL	Quantity needed For LEReC	Purchase total for LEReC
Beam Profile Monitors - low energy	5	11	6
Beam Profile Monitors - high energy	0	3 (or 1)	3 (or 1)
Multi-Slit - transverse emmitance	0	3	3
Beam Current Monitors - ICT	1	1	0
Beam Current Monitors - FC electronics	2	2	0
Beam Current Monitors - DCCT	2	2	0
Beam Loss Monitor - PMT	14	14	0
Beam Loss Monitor - Heliax	5	5	0
Beam Loss Monitor - Heliax (dump only)	24	24	0
Beam Loss Monitor - Thermal camera	1	1	0
Beam Loss Monitor - pin diode	8	8	0
Beam Position Monitors - dual-plane button cube, Libera electr.	14	10	0
Beam Position Monitors - 28mm dual-plane button cube, BNL elctr.	0	16	16
Beam Position Monitors – for ions in cooling section – BNL electr.	0	16	16
Beam Halo Monitors	6	6	0
Recombination Monitors (in cooling section)	0	4	4
RF cavity tuners & motion control	3	6	3
Totals	85	132	48

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ICT for Bunch Train Charge Measurement

Instrument used for commissioning, troubleshooting and confirming that short bunch train charge measurements match the laser based charge estimations.

<u>Bergoz</u> ICT-CF6-60.4-40 05:1-H-UHV-THERMOE

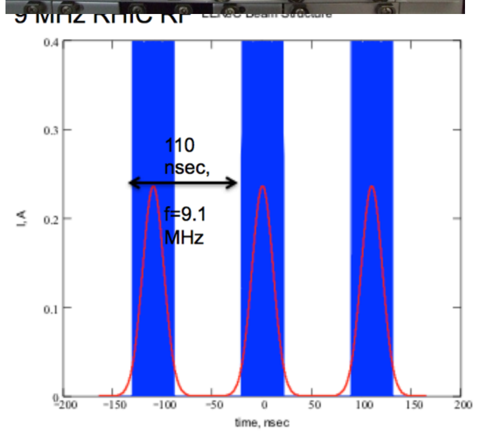
Integrating type, In-flange CT
- Bergoz BCM-IHR electronics
- Sensitivity of 1pC (minimum)
- Background Subtract
- Noise ≈ 1 – 10 pC (beam charge)
- Calibrated

Run in burst mode to 10kHz repetition at up to 7us long pulse trains

⇒ Single to ~1/2 turn of macrobunches,
⇒ Measured every ~10th turn (*Maximum*)
⇒ 1 Hz data log rate (*Typical*)

Mechanical details:

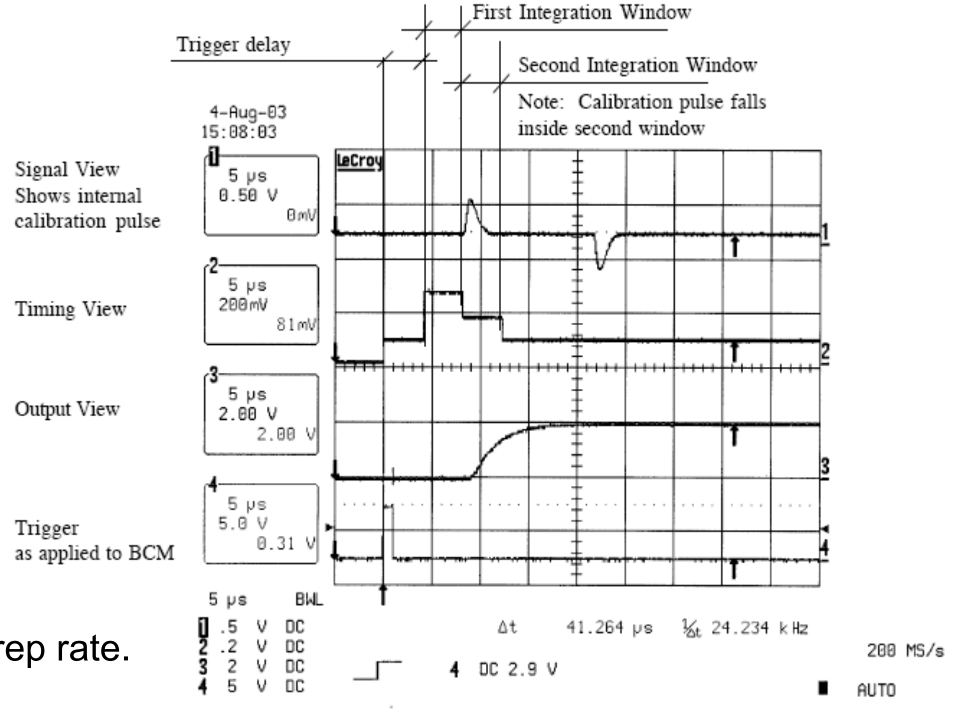
60.4mm ID
40mm axial length
Rad-Hard option
Bakeable to 150C, plan 48h at 150C
- Separate bake-out zone
- Internal TC, type-E



Example Bunch Structure for Phase I:

Train of 3 nC macrobunches @ 9.1MHz rep rate, each containing 30 x 100 pC bunches @ 704MHz rep rate.

Signal processing timing diagram: 0.1us > Gate width <7us



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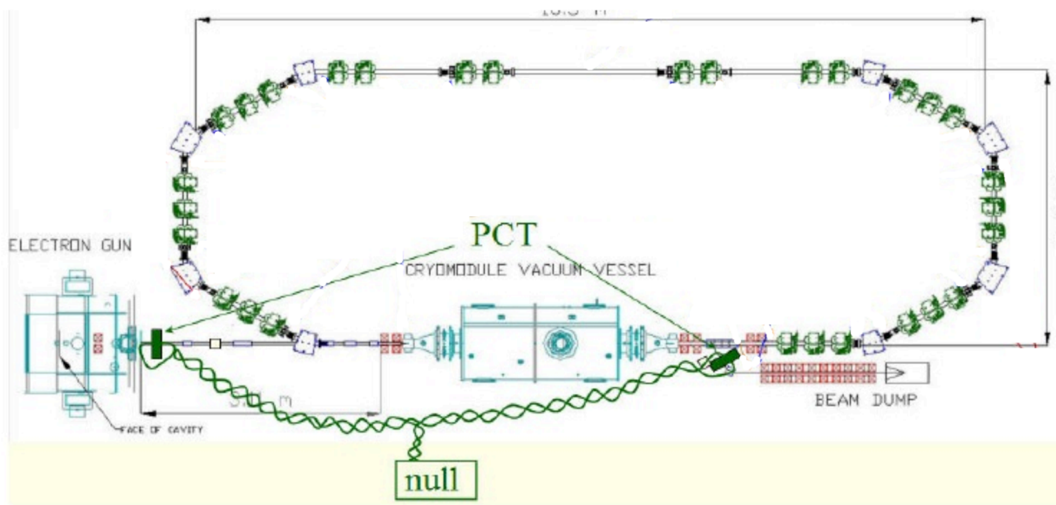
December 8-10, 2014

Differential DCCT System – Carried over from ERL

- Used for commissioning, trouble-shooting & logging of average current
- DC – 10kHz bandwidth
- 20mA & 200mA ranges
- 5uA resolution

Modes:

- Absolute Gun & Dump currents
- Differential Gun – Dump current for Machine Protection (10uA loss budget)



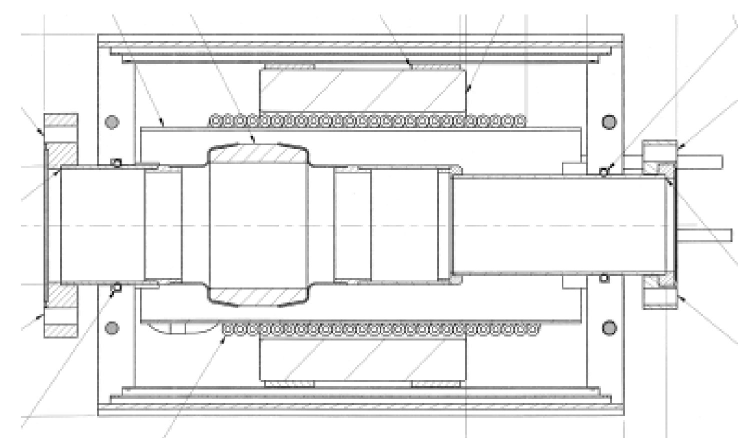
Bergoz NPCT system

The DCCTs in the injector & dump lines are configured in a **zero-flux Differential** arrangement; where the dump current measurement drives a current source threaded through both DCCTs' calibration loops to minimizethe dump DCCT output; thereby making the injector DCCT's output the current difference .

Bergoz model # NPCT-S-115 New Parametric Current Transformer, with options:

- 115mm ID
- Very high resolution ($<1uA/(Hz)^{1/2}$)
- Radiation resistant sensor

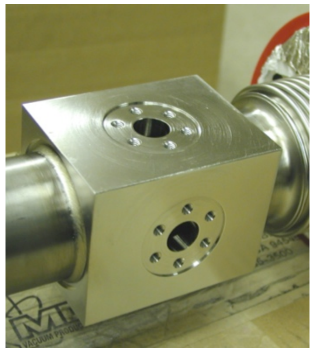
<u>BNL designed enclosure:</u>
Calibration winding
Water cooling (80C max bake)
Mu-metal shield



BPMs in Electron Beam Transport (10 Locations)

e-Beam Transport & Dump Line:

- 9 dual plane stations
- Reuse ERL Button Pick-ups
- 9.3 mm diameter
- SMA Connector
- 1- 4pF, 5% matching
- 200C bake-out



Libera Brilliance Single Pass Electronics
Worked Closely with I-Tech to modify the standard LBSP for our ERL facility.

Advertised features:
- High accuracy, Low drift
- Built-in custom configurable FPGA processor
- GB Ethernet, Beam inhibit capability
- Average orbit mode: 0.1-100mA sensitivity,
- Single bunch mode; up to 200Hz trigger rate

Low energy beam line pick-ups for DC Gun option:

- Dual plane station
- 1 location between Gun and accel cavity
- Cornell style stripline BPMs for 400keV beams

Courtesy B. Dunham 2013

Operational Conditions:
- 0.5-5nC (0.1mA @ 1nC)
- Low current: average measurements @ 200Hz
- BPMs common to Ion & e-beams: Pre-calibrate BPMs for e-beam using ion beam

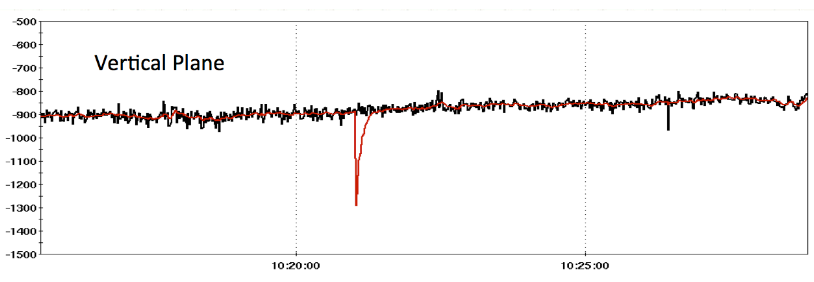
BPMs in Cooling Section (14 Locations)

Shared Pick-Ups:

One dual plan station at each solenoid is shared by two electronics boards, one measuring ions and one measuring electrons.

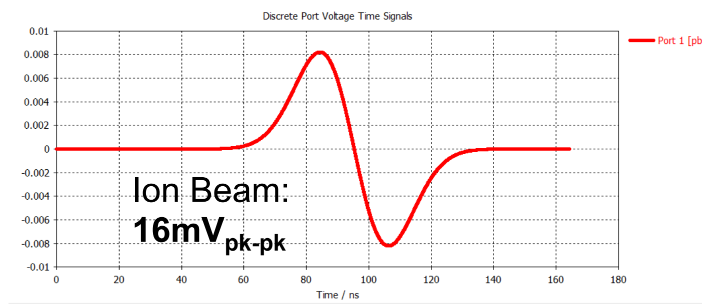
BNL Zync Electronics Design:

- VME Form Factor
  - Use RHIC Controls Infrastructure
- Configurable Front End RF Section
  - **39 MHz** for Ions
  - **700 MHz** for electrons
- 4 x 400MSPS A/D Converters
  - 2 Planes of Measurement / Board
- Integrated Front End Computer
  - FEC & FPGA on Single Chip (Zynq)
- Ethernet Connectivity (x2)
  - Controls Network
  - High Speed Interface for Feedback
- Test results below at the ATF with 9.3mm buttons showed better than 100um accuracy and 10um precision.

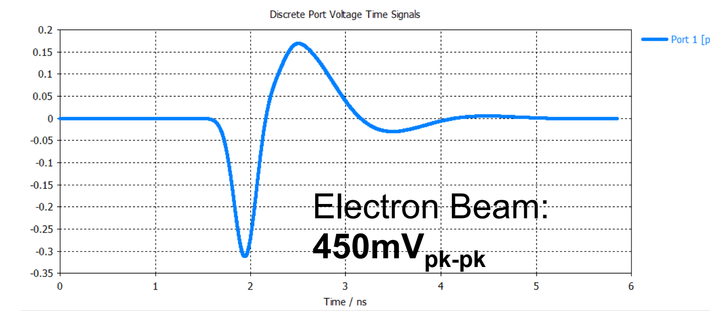


Signal Simulations:

Simulations were made with the short electron bunches and long ion bunches to determine expected signal amplitudes on the buttons.

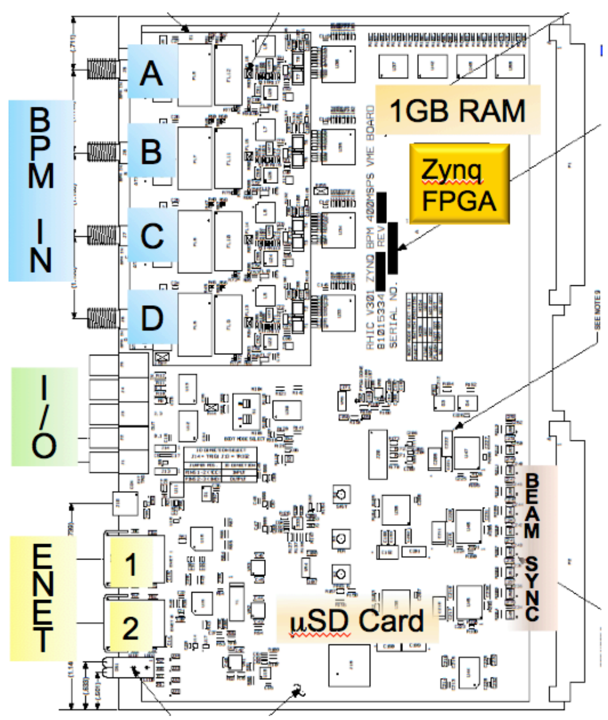


γ= 4.1
Ions/bunch = 7.5E8
Charge/bunch = 9.48E-9 C
RMS length = 3.2 m



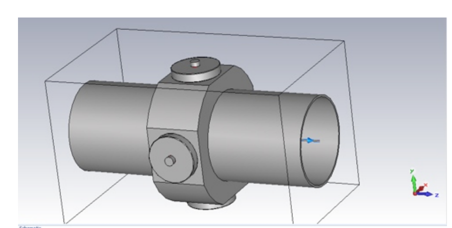
Simulations: Courtesy of Peter Thieberger

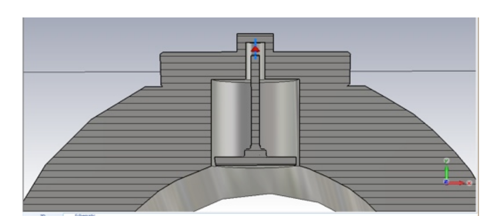
γ= 4.1
Charge/bunch = 100 pC
RMS length = 100 ps
RMS length = 30 mm



New Pickup Design:

- Large Dia. BPM Housings
- 28mm buttons
- N-Type feedthrough
- MPF Q7031-1





Profile Monitors – Transfer from ERL

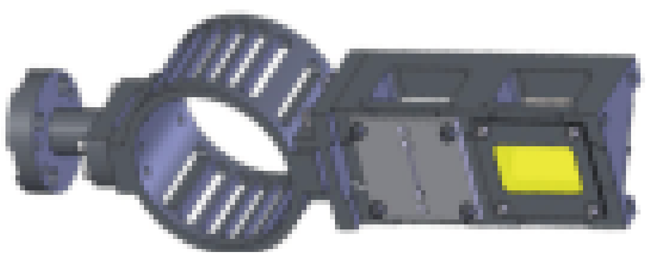
<u>5 Profile Monitor Stations (Low power only)</u>
- Injection (1), Transport (3), Dump (1)
- Radiabeam product as per BNL specification
- LEReC transport size compatible with ERL

<u>Plunging head detail:</u>
Impedance match + two diagnostics positions

(2) Low Energy PM

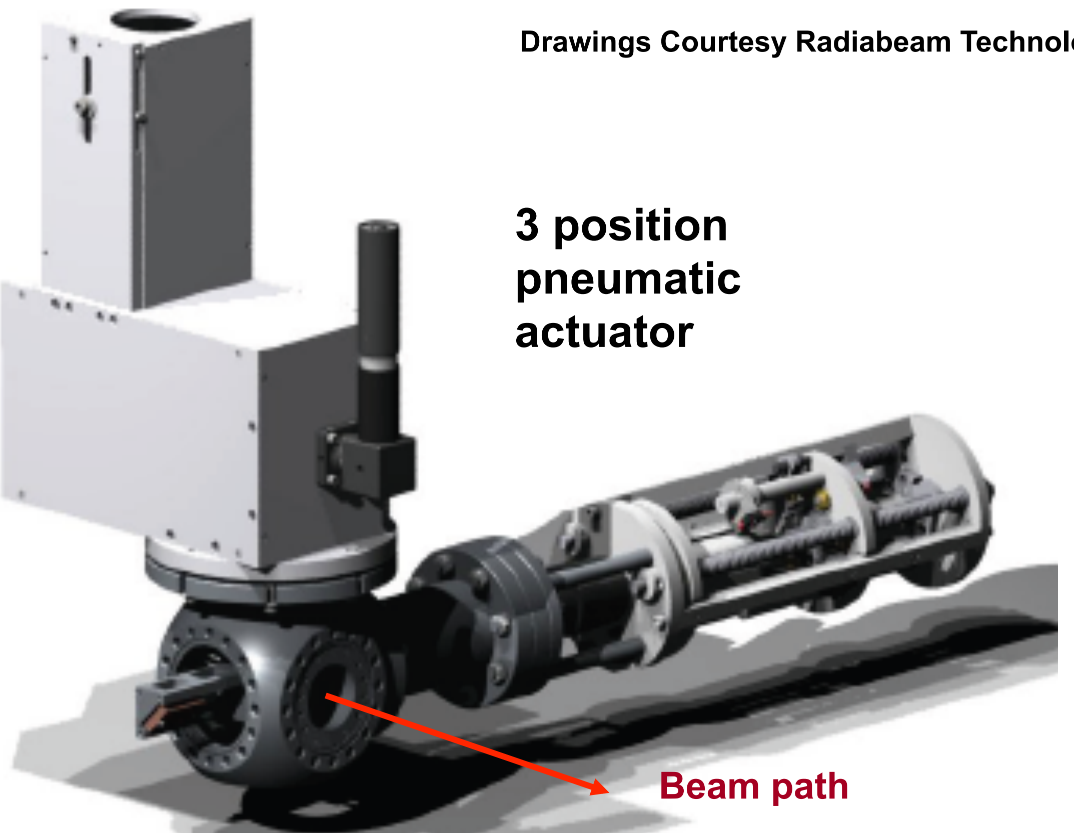
40mm YAG

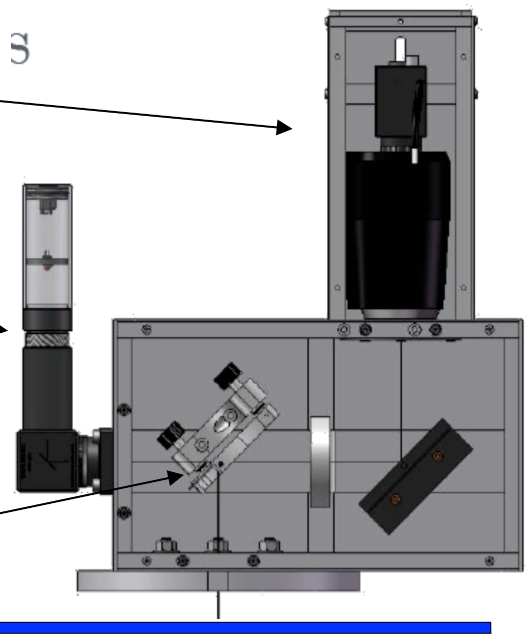
(3) High Energy PM



25x15cm YAG

Drawings Courtesy Radiabeam Technologies





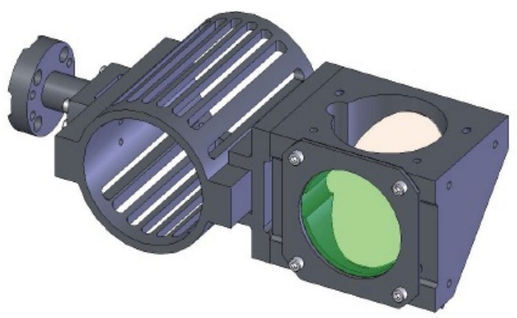
<u>YAG:Ce Screens:</u>
100u thick crystal, Crytur
For low intensity beams:
10's of pC at 2MeV, and ~1 pC at 22MeV

<u>OTR foils:</u>
Silicon wafer 250u thick, 1000Ang Al coating.
For higher energy & intensity beams:
20MeV, & > ~130pC

Profile Monitors – New designs for Cooling Section

<u>Low Power</u> <u>profile measurement</u>

- 4 or 6 stations
- Two Position plunger (similar to ERL Design)
- 100um thick YAG crystal
- Impedance matching cage
- Large cube for 5” beam pipe
- Same optics as ERL design



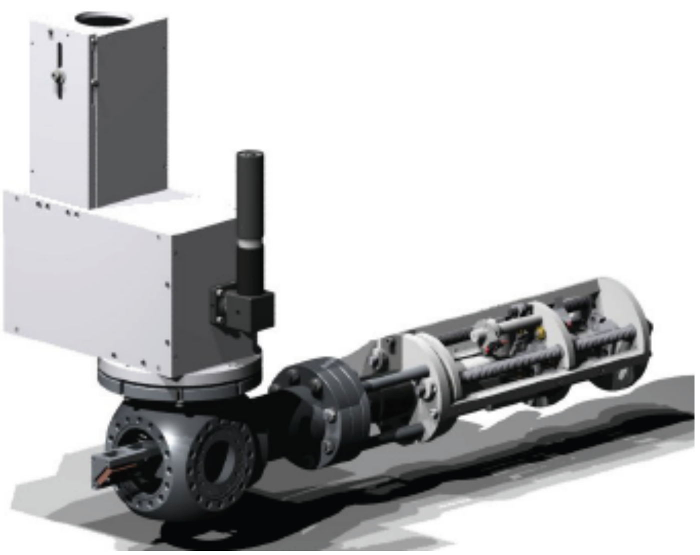


Photo courtesy of Radiabeam

<u>High Power</u> <u>profile measurement</u>

- 2 stations
- Compact offset cam design
- 9 µm carbon fiber passes beam only once @ 20 m/s
- accelerate/coast/decelerate in two rotations
- PMT detects X-rays generated by the scattered electrons

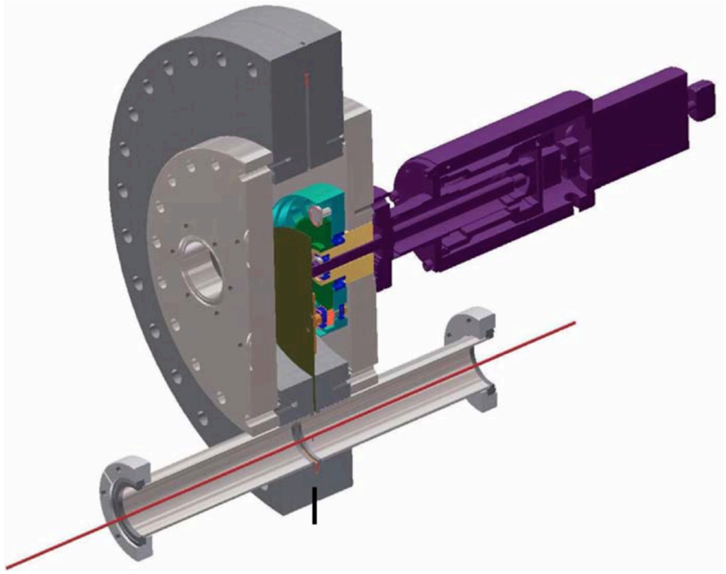
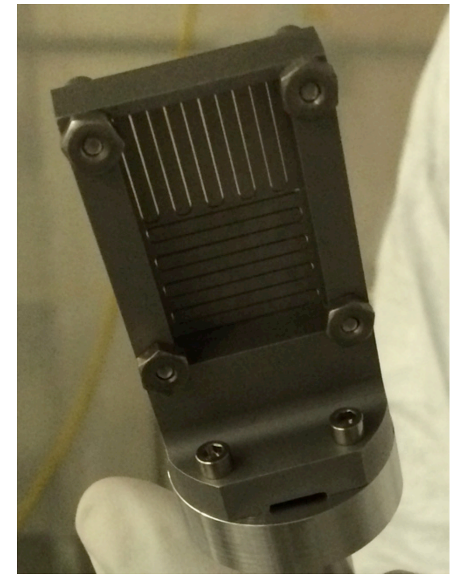
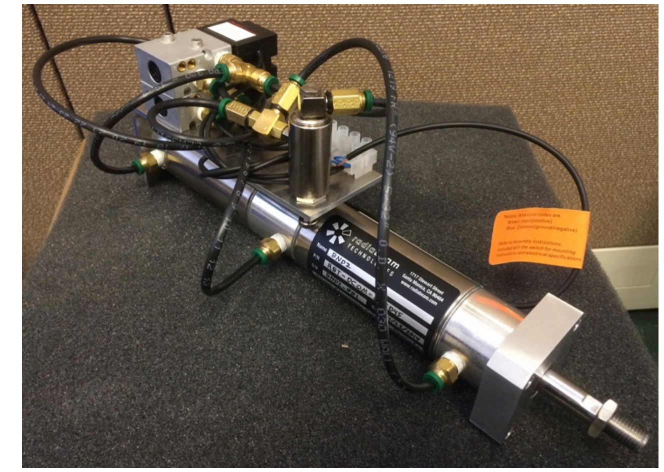


Photo courtesy of B. Dunham, Cornell

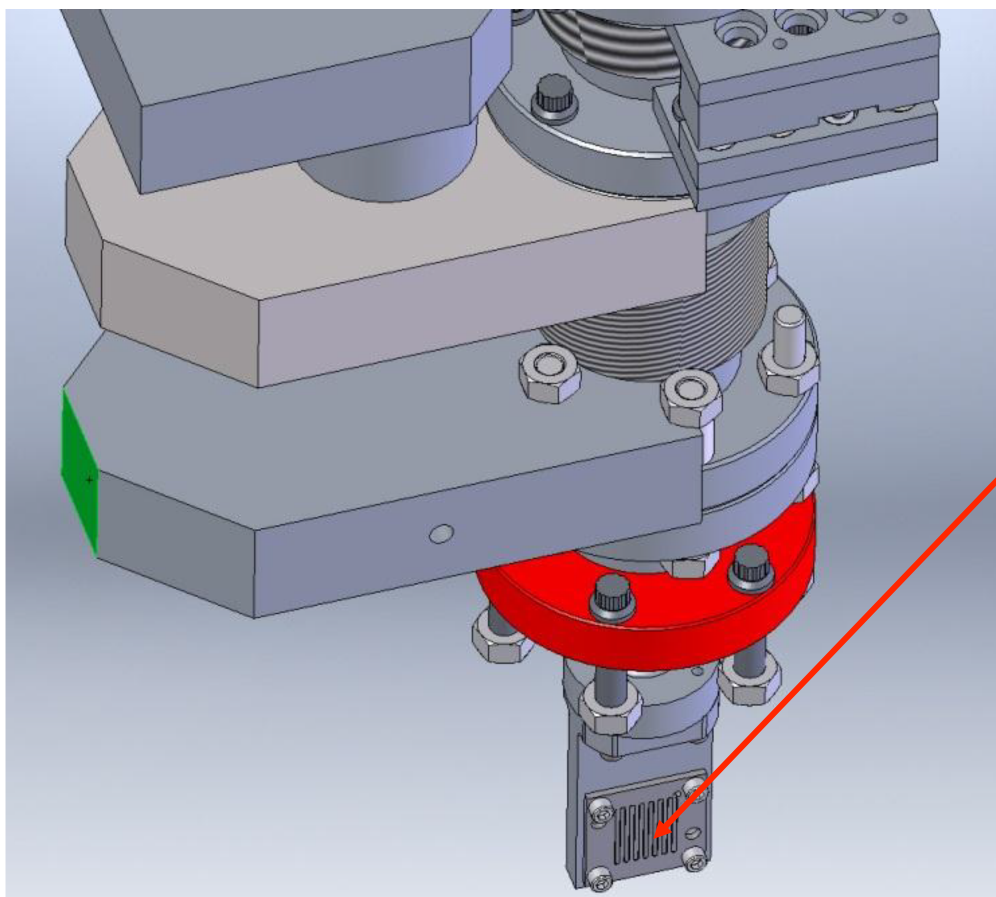
Emittance Slit Measurement

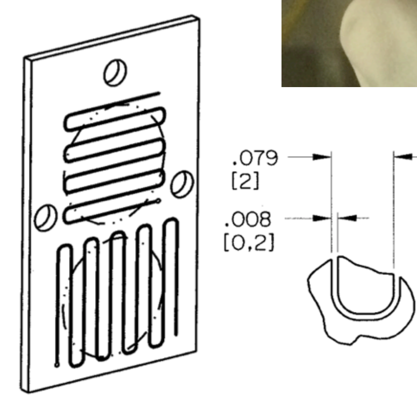
- Low Power Operations Only
- New Dual axis design for Horizontal & Vertical measurements.
- Positioned 0.16 – 1 m upstream of profile monitor
  - Final spacing TBD…
- Tungsten Slit mask, optimized for beam parameters
  - Mask 1.5mm thick… # slits & TBD…





Dual Station Actuator retrofitted for new dual axis mask.





ANALYSIS:
An algorithm was developed for analyzing the image from a multi-slit mask for emittance measurement.

Future plans are to automate the image analysis for on-line processing and data logging.

Intensity Distribution at mask

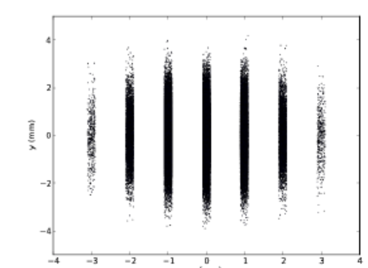
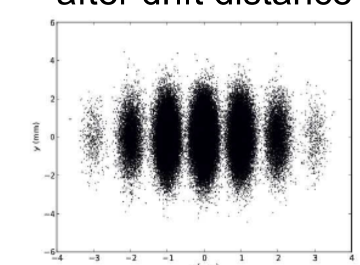
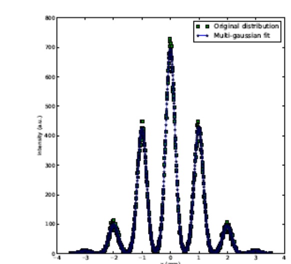


Image on profile monitor after drift distance





BROOKHAVEN NATIONAL LABORATORY

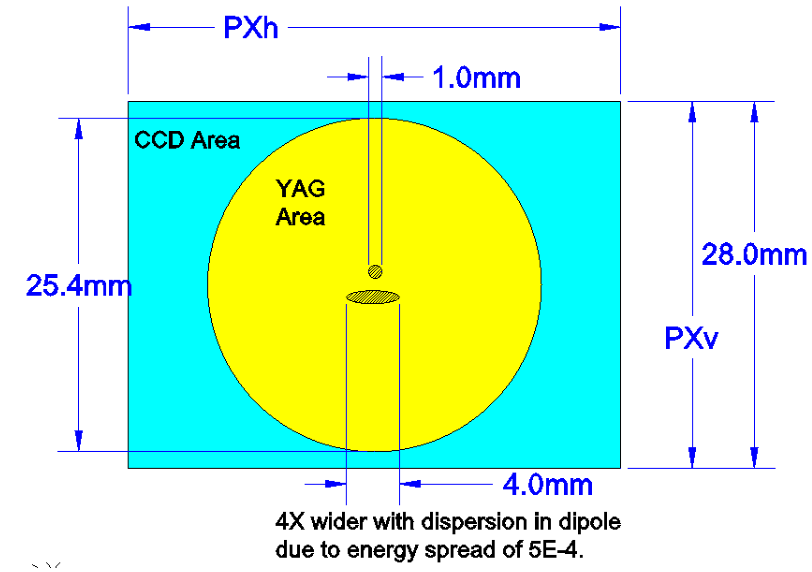
Office of Science
U.S. DEPARTMENT OF ENERGY

December 8-10, 2014

Energy Spread Measurements – 2 Locations

- Max. Energy Spread: $\Delta p/p = <5e\text{-}4$
- Beam Size (d): 1mm (dia.)
- Double Slit before dipole & drift to YAG
- May use **Quad** to increase resolution between cooling sections
- *Considering alternatives:*
  - *Dedicated energy spectrometer beam line*
  - *Cornell's method of using deflecting cavity*

Image of YAG as projected onto CCD

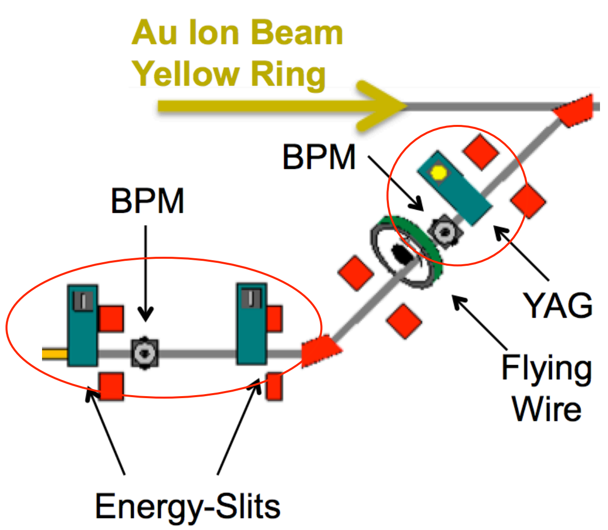


- 2MP CCD: 1292_h X 964_v px
- $\text{Pitch}_{YAG} = \text{proj-H}_{CCD}/\text{px}_v$ $= 29\mu m/px$

Before Cooling Sections

- $\sigma_\delta = 750\mu m$
- Resolution = σ_δ / Pitch_{YAG}
- 750μm / 29μm/px = 25 px

➔ 4% Resolution

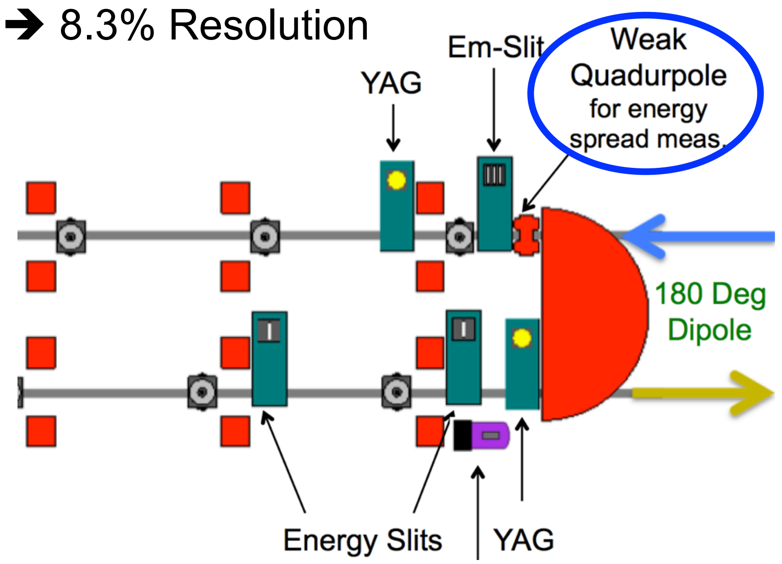


$\sigma_\delta = \eta\delta = 1.5m(5x10^{-4}) = 750\mu m$

Between Cooling Sections

- $\sigma_\delta = 350\mu m$
- Resolution = σ_δ / Pitch_{YAG}
- 350μm / 29μm/px = 25 px

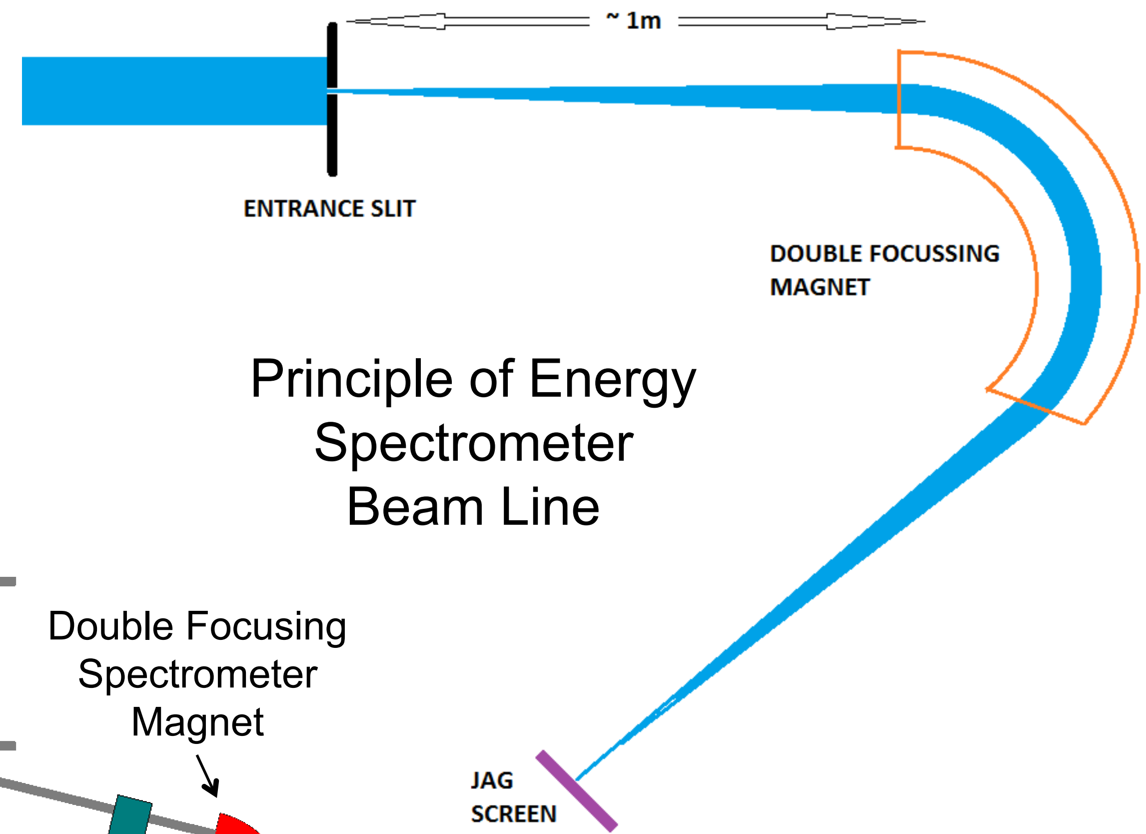
➔ 8.3% Resolution



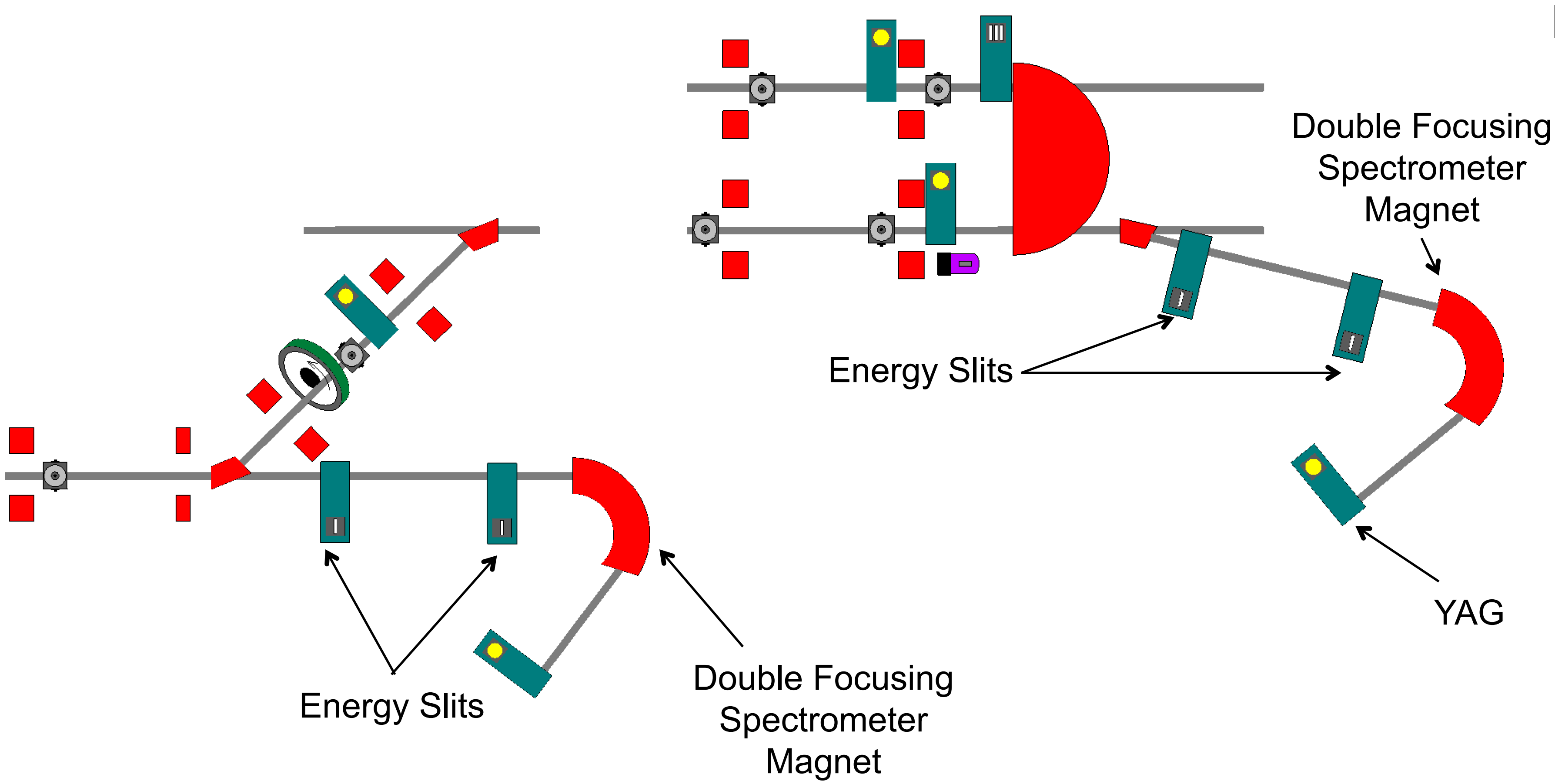
$\sigma_\delta = 2R\delta = 2(0.35m)(5x10^{-4}) = 350\mu m$

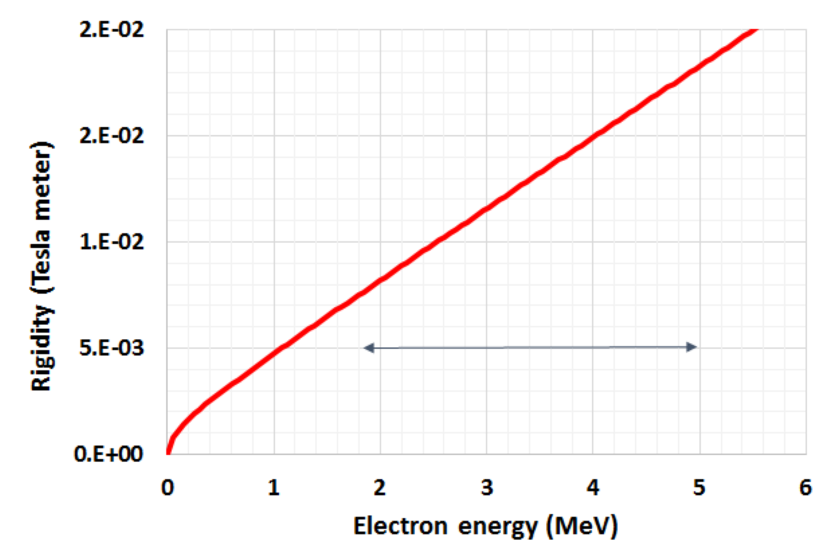
Energy Spread – Alternative Energy Spectrometer B/L

- Max $\Delta p/p \approx 5\times10^{-4}$
- Would require two dedicated diagnostic beam lines
  - On straight after dog-leg
  - After 180° cooling section dipole



Principle of Energy Spectrometer Beam Line

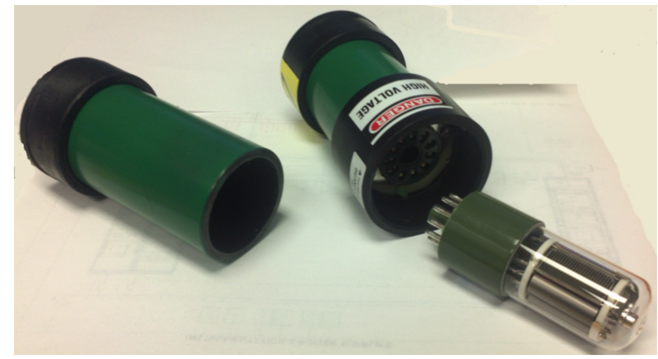


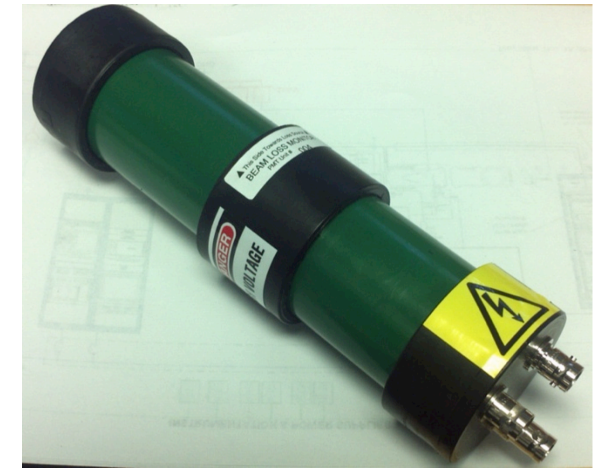


Beam Loss Monitors - Transfer from ERL

Beam Loss Monitors

PMT Detector (similar to JLAB-CEBAF, FEL)
(Hamamatsu R11558 PMT)
Fast (<<1us), HV tunable for sensitivity adjustments
50dB DR (5nA – 100uA from tube)
Limited coverage, small cross section

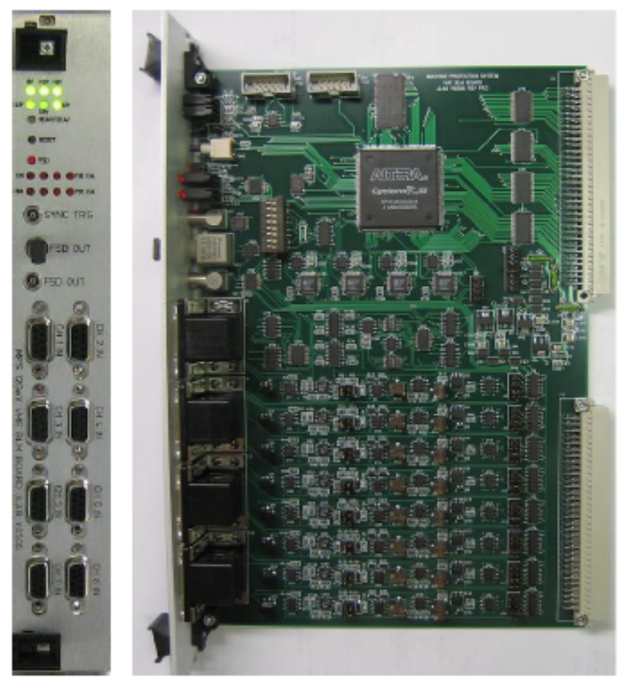




BLM Electronics
The new version of BLM electronics developed at JLAB for the 12GeV upgrade will be used for the PMT detectors.

We have three 8-ch modules for ERL.

Controls integration is underway.



- Provide both machine protection and diagnostic functions.
- Instantaneous readback of beam loss.
- 16 bit digital output for integrating and logarithmic signals.
- Fast response, << 1 μs response time for integrating, 10 nA[2] for log.
- Wide dynamic range (>50 dB) for logarithmic signals.
- Built-in self test and onboard signal injection.
- FPGA controlled.
- Local data buffer for integrating and logarithmic signals.
- VME interface and fully integrated into EPICS.
- Pulse beam measurement and continuous monitoring.
- Low cost (≲$100 per channel).

New Beam Loss Monitor for 12GeV Upgrade
J. Yan, K. Mahoney, ICALEPCS 2009

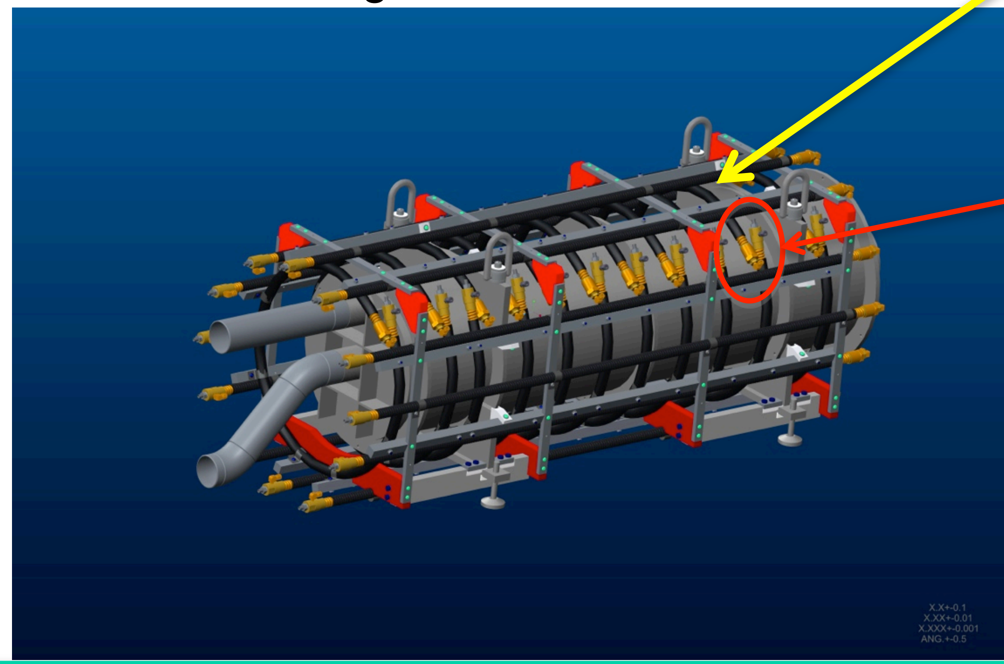
Infrared Camera (FLIR A310)

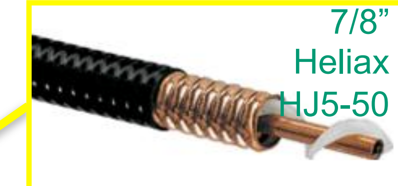
Check for beam pipe heating, or losses other detectors can't see.
Remote image display & storage, Ethernet communication.

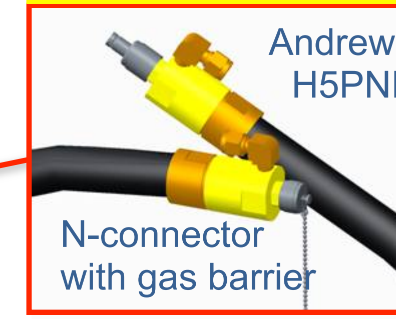
Other Beam Loss Monitors – Transfer from ERL

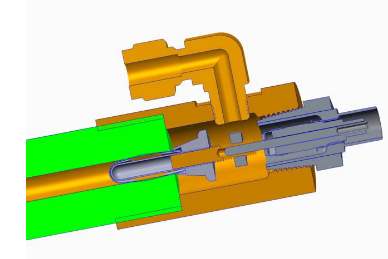
- Dump BLM Array
- IC's
- PIN Diodes
- Heliax in bends

Beam Dump 24 Ch of Heliax BLMs
Long Ion Chambers made of air dielectric coaxial cable, argon filled, biased to -200V

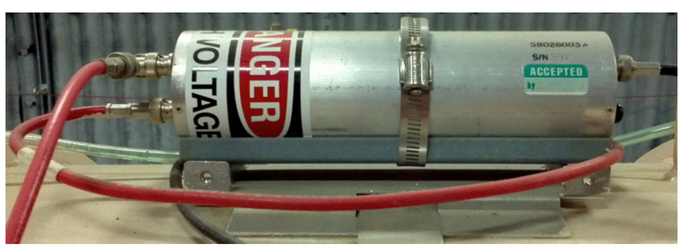


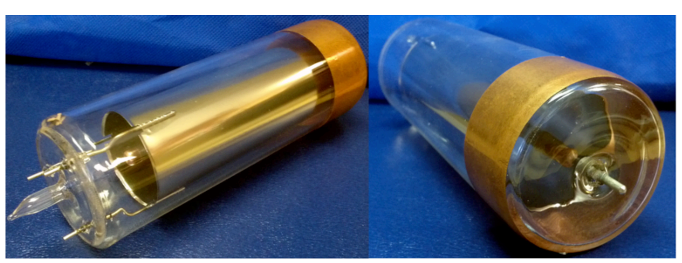




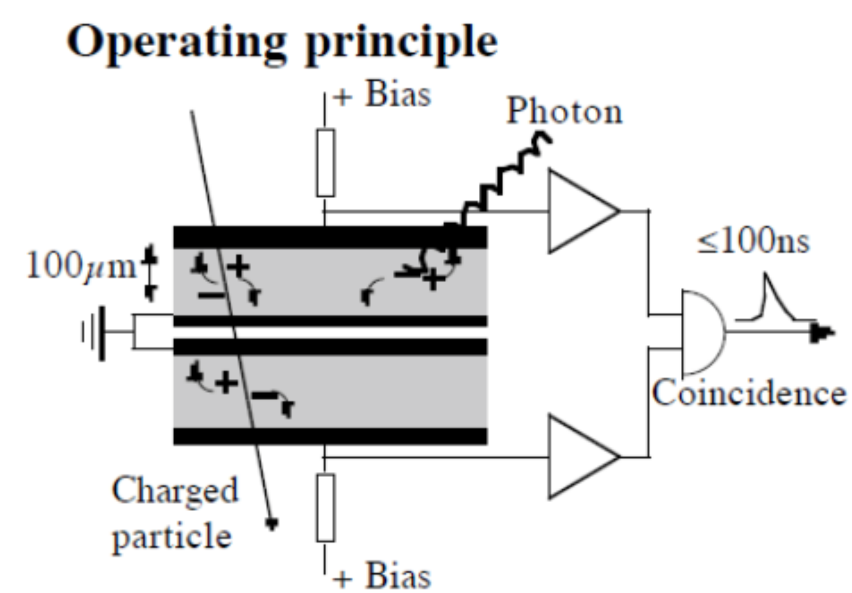


Ion Chamber (IC) BLM: Ion chambers made of 113cc glass tubes with 0.95 atm of argon and nickel electrodes, +1400V biased. ~400 installed in the RHIC ring





PIN Diode BLM:
Solid State compact design,
coincidence compensated,
10 MHz counting rate,
namic range > 10^8,
recovery time <100ns,
Radiation hardened
to 10^8 Rads

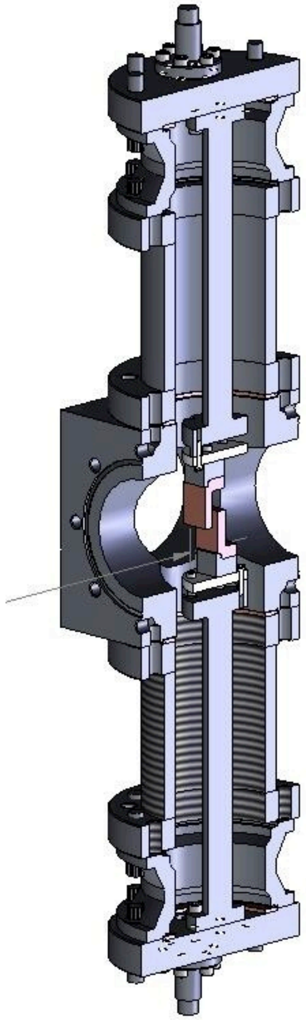


Halo Monitors -Transfer from ERL

Goal is to measure electron beam halo.

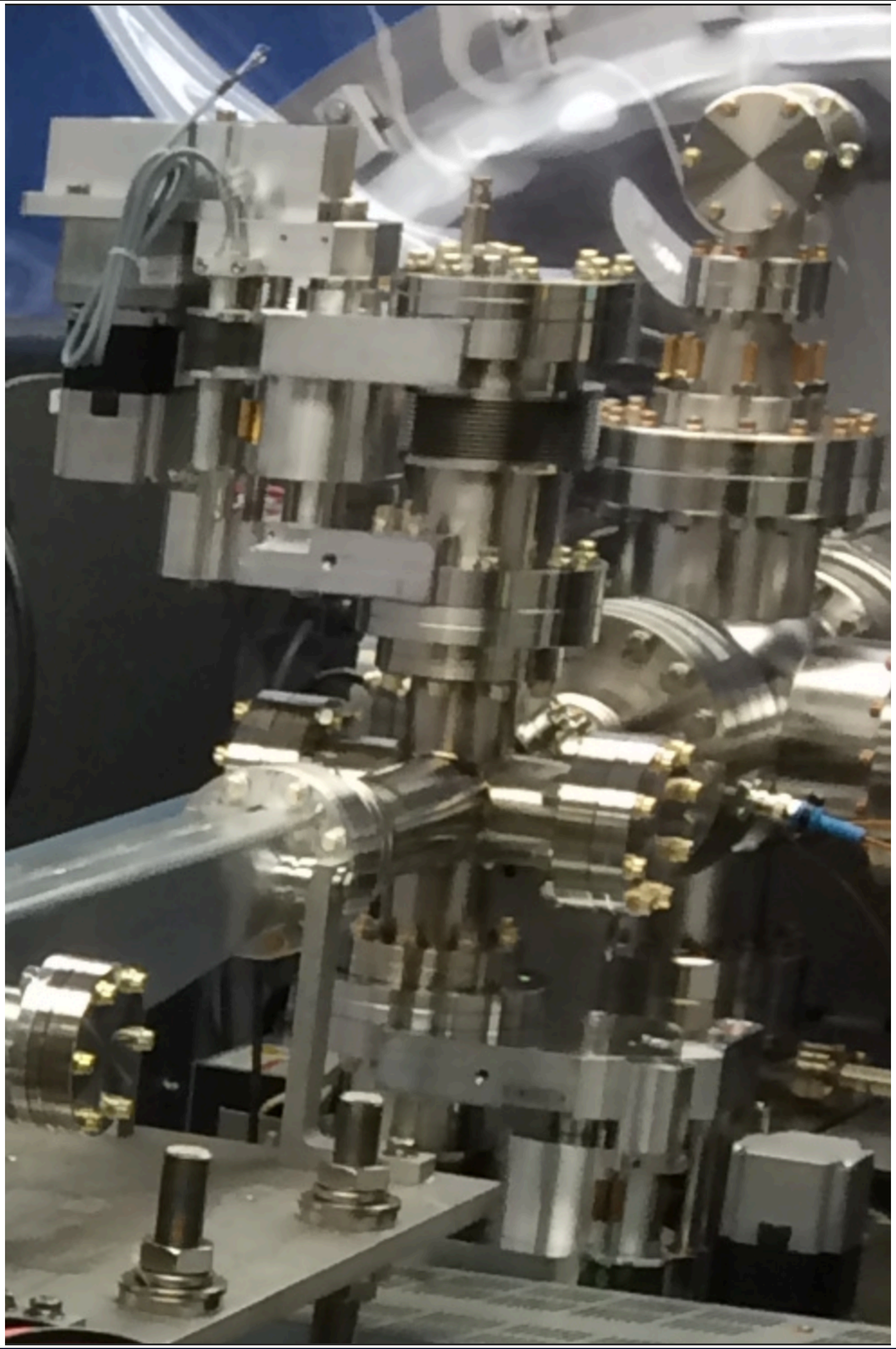
3 pairs of stepper controlled moving copper jaws with current measurement from the blades.

- Injection:
  - One horizontal pair
  - One vertical pair
- Transport:
  - One vertical pair



The original purpose was for use at the ERL R&D facility to measure halo at 2MeV to characterize the halo and guide new collimator design.

These devices are located in the zig-zag just downstream of the gun.



Vertical Pair
installed in the ERL
injection straight

Recombination Monitors

E-Ion RECOMBINATION:

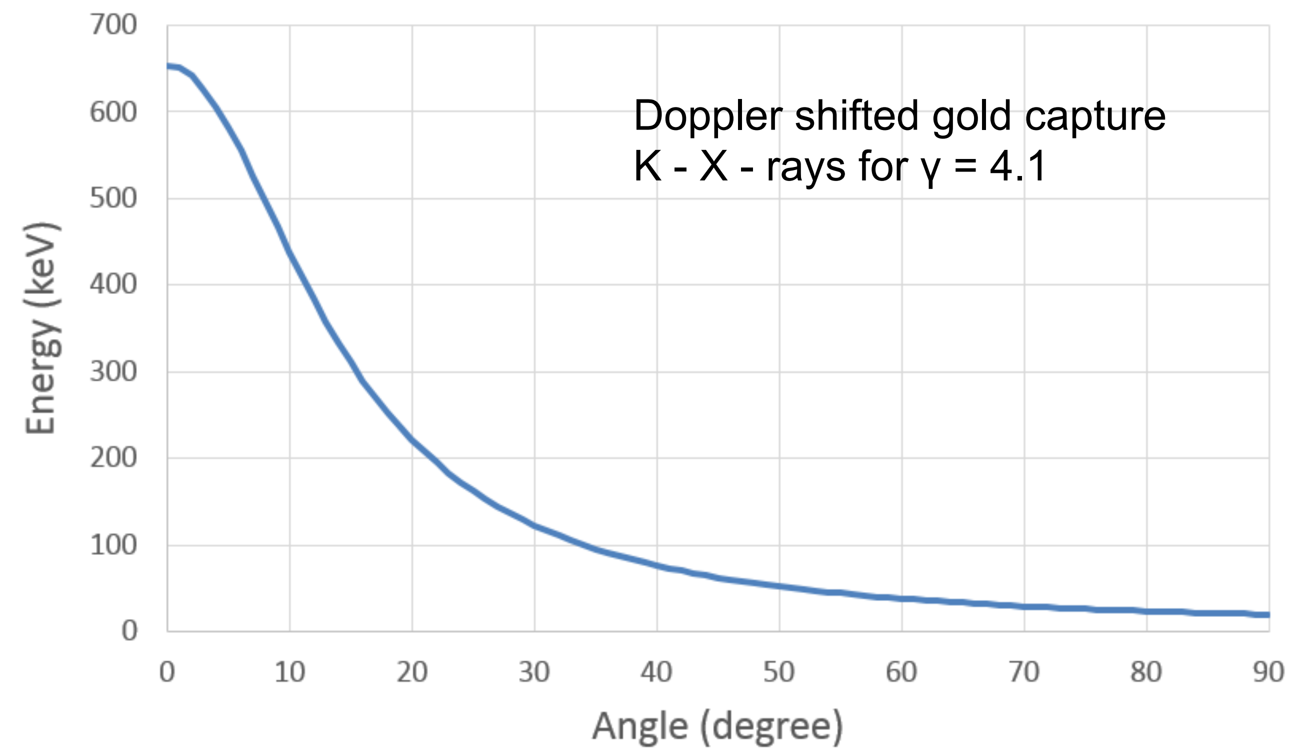
- $Au^{+79} \rightarrow Au^{+78}$, Expected rate ~5e6 per second
- Creates ions of wrong charge
- Generates X-rays in cooling section
- loss rate ≈ alignment

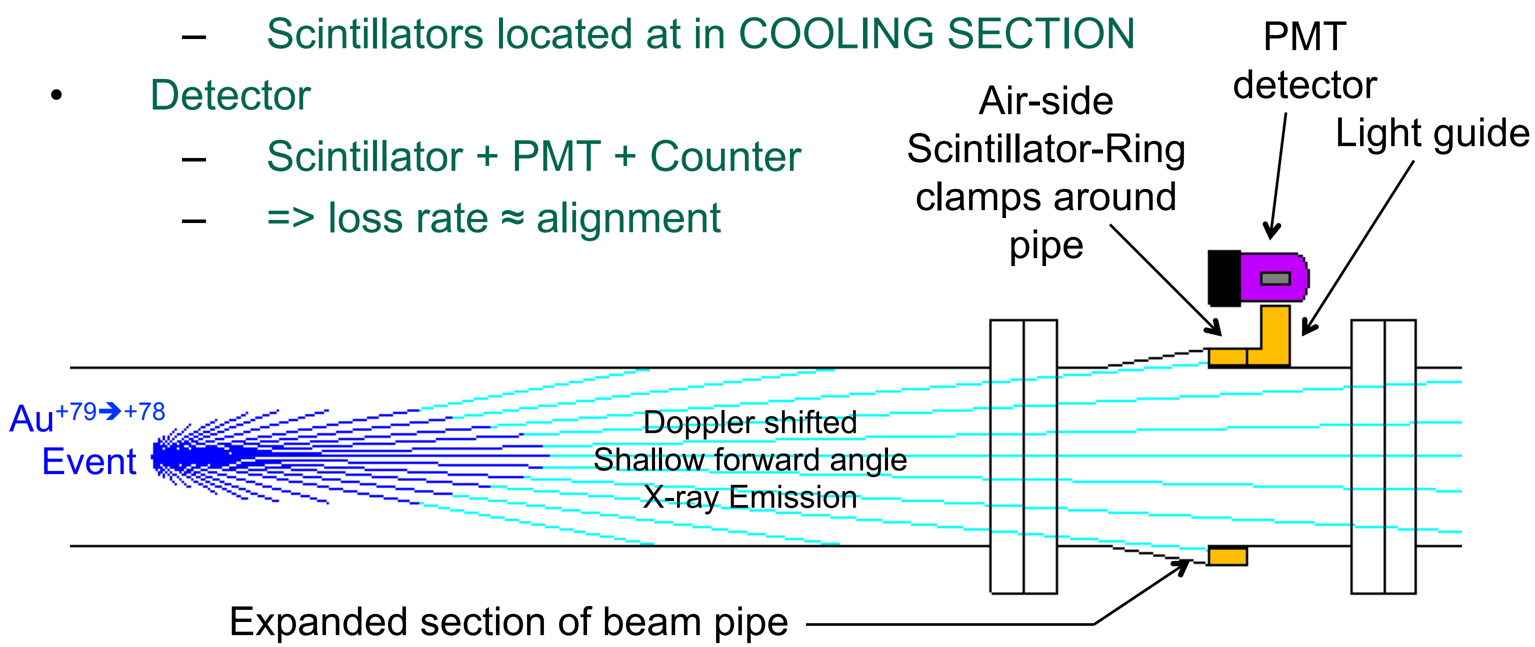
ION (wrong charge) **COLLECTION:**

- Lost at predictable location (collimators)?
- Detector: PMT + Counter
- ! Lattice simulation predicts lattice aperture acceptance of Au^{+78} ions ! => **MAY NOT WORK**

RADIATIVE RECOMBINATION DETECTION:

- Recombination radiation
  - 10-80keV x rays emitted a shallow forward angle
  - Scintillators located at in COOLING SECTION
- Detector
  - Scintillator + PMT + Counter
  - => loss rate ≈ alignment





$$for\ \gamma = 4.1$$

$$\beta = \sqrt{1-\frac{1}{\gamma^2}} = 0.970$$

$$E' = E \times \frac{\sqrt{1-\beta^2}}{1-\beta\cos(\theta)}$$

$$Gold\ \ K-shell\ \ binding\ energy = 80.7\ keV$$

$$E' = 80.7\ keV \times \frac{\sqrt{1-0.97^2}}{1-0.97\cos(\theta)}$$

Courtesy of Peter Thieberger

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RHIC Diagnostic Systems

Instrumentation providing evidence of cooling:

RHIC BPM System – will accurately measure the ion beam position with enough accuracy for efficient cooling.

Schottky Cavity – spectra of the beam will show peaks resulting from cooling.

IPM – Ionization Profile Monitor will show changes in transverse beam profile resulting from cooling.

Legend

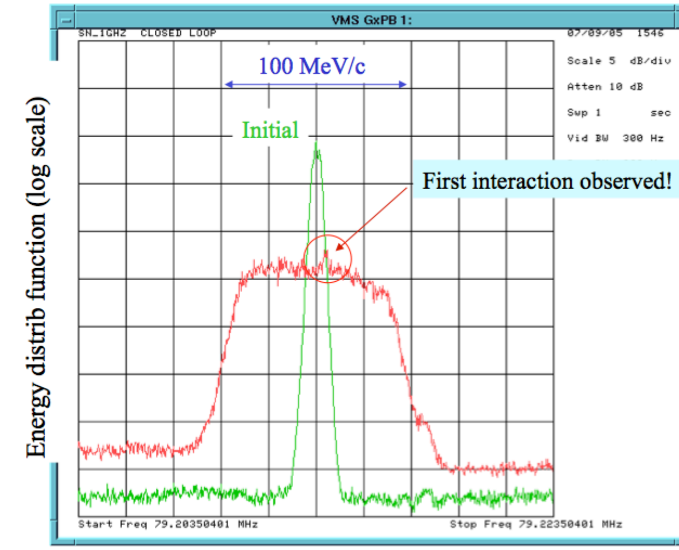
Green: before cooling

Red/Blue: after cooling

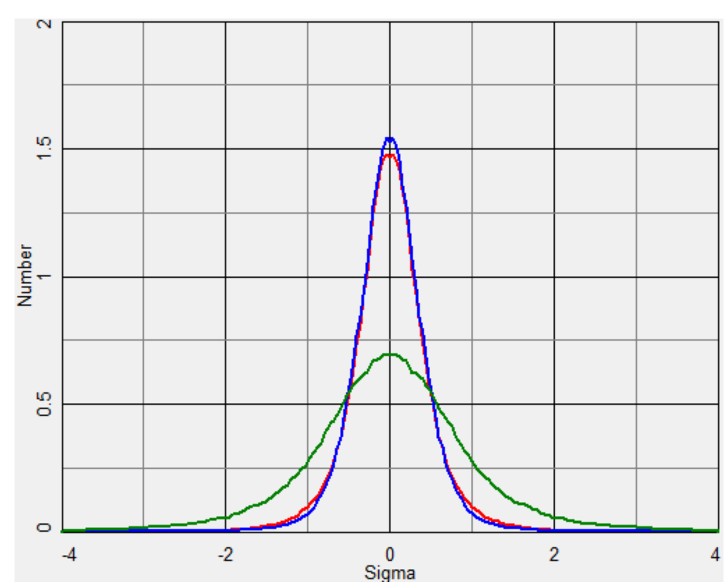
Schottky Spectra

Cooling Measurement Techniques at FNAL

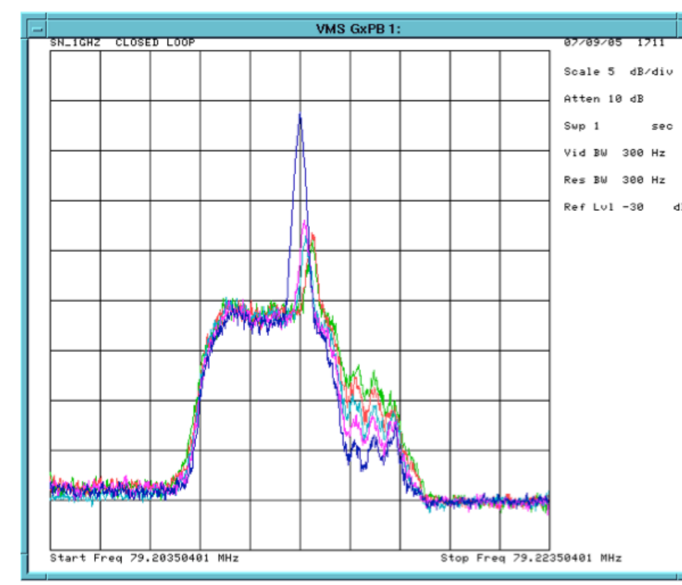
Courtesy S. Nagaitsev



Onset of cooling



Simulation of change to transverse profile with and without cooling.



Properly Aligned cooling beam

Summary

We have currently identified a set of instrument types intended to meet the requirements. We are refining the actual locations, quantities and resolution requirements and instrument capabilities.

Current activities include:

- Simulations of BPM signals to steer pick-up and electronics design & procurements.
- Layout of cooling sections to steer specifications of profile monitor's & slits.
- Search for mature wire scanner design adaptable to 5" aperture beam line.

Open issues include:

- **BPM's**
  - new electronics design with custom RF front-ends
  - ability to distinguish between ion & electrons on shared pick-up electrodes
  - new 28mm button design vs new stripline design under solenoids (space constrained)
- **energy spread measurement, considering options:**
  - double slit YAG dispersion measurement in dogleg & 180deg dipole
  - dedicated spectrometer beam line in two locations
- **High power transverse profile monitor: considering fast wire scanner** location & development
- **Recombination monitor** design (RHIC background noise)
  - Radiative recombination monitor detects x-rays in cooling region.
  - Au^{+78} collection challenge.

Moving forward, goals to support the summer '15 cooling section installation include:

- Development of **specifications** for procurement of **profile monitor**'s, **slits**, and **wire scanner's**
- Development of an air-side design of the recombination monitors

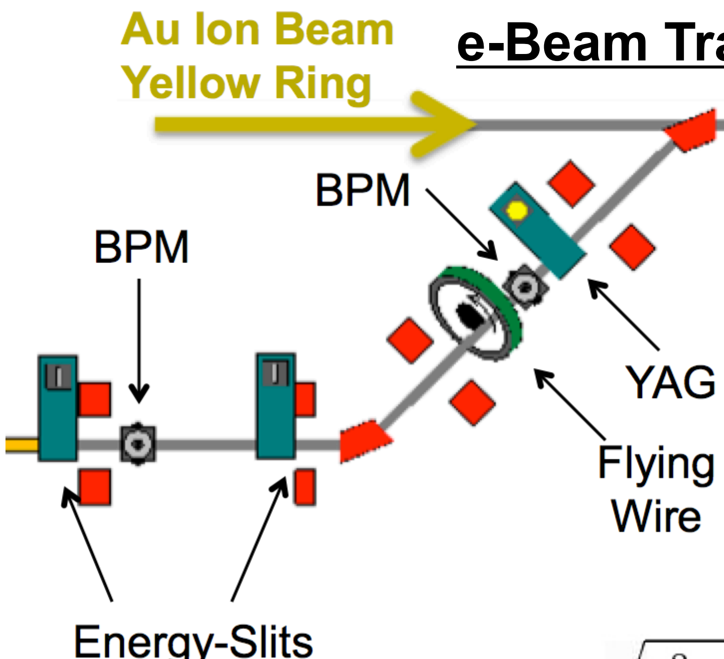
Existing instrumentation technology and experience gained at RHIC, ERL and CeC will reduce risk and allow us to measure beam parameters with required accuracy.

Issues to address from Last Review

Diagnostics:

- 1. Specify diagnostics in the cooling zone to meet the requirements.
- 2. A commissioning and tuning plan should be drafted that proposes the method and the diagnostics necessary to achieve the required beam parameters through beam based set-up and measurements.
- 3. The diagnostics and method to match the electron energy to the ion energy has to be detailed.
- 4. The strategy for spatial overlap of electron and ion beams should include sufficient diagnostics in the cooling section.
- 5. Consider the detection of Au ions after recombination as a means of measuring the cooling process efficiency.
- 6. Diagnostics must be able to measure the electron beam path and the electron beam transverse distribution for optimization of the beam parameters and the cooling. Diagnostics must also allow the matching of the electron beam with the ion beam in the transverse degree of freedom.

e-Beam Transport & merger



$$\sigma_m = \sqrt{\sigma_\delta^2 + \sigma_\beta^2}$$

$$\sigma_\delta = \eta\delta = 1.5\text{m}\,(5 \times 10^{-4}) = 750\ \mu\text{m}$$

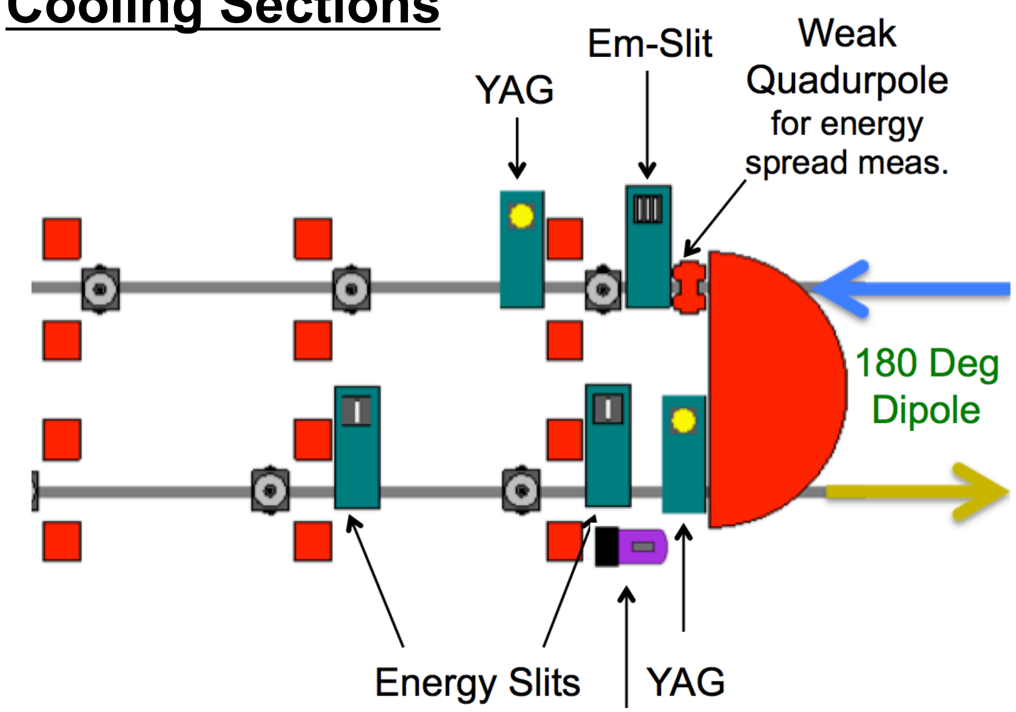
$$\sigma_\beta = \sqrt{\epsilon_{rms}\beta},\ \gamma\epsilon_{rms} = 2.5 \times 10^{-6}\ \text{m rad}$$

$$= 5\ \text{mm}\ (\beta = 40\text{m})$$

$$= 500\mu\text{m}\ (\beta = 0.4\text{m, solenoids off})$$

$= 40\ \mu\text{m}$ (the contribution of the emittance σ_β is greatly reduced with additional pair of 30 μm slits spaced by 3 m located 4 m upstream of YAG or wire)

Cooling Sections



$$\sigma_m = \sqrt{\sigma_\delta^2 + \sigma_\beta^2}$$

$$\sigma_\delta = 2R\delta = 2(0.35\ \text{m})(5 \times 10^{-4}) = 350\ \mu\text{m}$$

$\sigma_\beta = 30\ \mu\text{m}$ (the contribution of the emittance σ_β is greatly reduced with the additional pair of 30 μm slits spaced by 3 m located 3 m upstream of YAG or wire)